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AIR QUALITY FORT FRANCES

Annual Report, 1976

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AIR QUALITY

FORT FRANCES

ANNUAL REPORT, 1976

ONTARIO MINISTRY OF THE ENVIRONMENT

June, 1977

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SUMMARY

An air quality assessment programme, begun by the Ontario Ministry of the Environment in Fort Frances in 1972, continued in 1976 with vegetation injury assessment and sampling, moss bag exposure experiments, dustfall and suspended particulate measurements, sulphation rate determinations, and continuous hydrogen sulphide monitoring. Most work was concentrated in the vicinity of two kraft pulp mills, which constituted the major local industrial sources of air pollution.

The severity and extent of vegetation injury attributed to kraft mill emissions declined in 1976, compared with 1974 and 1975, although sodium levels in foliage of Manitoba maple (*Acer negundo*) continued to be found at elevated concentrations near the Ontario-Minnesota Pulp and Paper Company mill in Fort Frances. Foliar chloride content was also slightly elevated. Reduced sodium concentration in vegetation north of the Boise Cascade mill, International Falls, was attributed to reduced emissions from a newly installed recovery furnace. A moss exposure experiment demonstrated the presence of airborne calcium and chloride contamination near the Fort Frances mill, but the technique was not effective as a detector for sodium under the conditions tested.

High dustfall levels, well above the Ontario criterion, were regularly encountered near the Fort Frances mill. Sodium sulphate and sawdust were important dustfall constituents. Dustfall decreased sharply when the mill was not operating. Above criterion concentrations of suspended particulate were also found from time to time in the same area. Sulphation rates, reflecting the presence of hydrogen sulphide and mercaptans, were highest near the Fort Frances mill and lowest at the site most remote from either source.

Excessive hydrogen sulphide levels were frequently recorded near the Ontario-Minnesota mill. The Ontario criterion was exceeded 1071 times during the year, and the maximum hourly average was 458 parts per billion (ppb). Lowest concentrations occurred during

the period when the mill was closed. An indication of improvement was noted in December, following introduction of additional emission controls. About 70 percent of high values were attributed to the Fort Frances mill and 22 percent to the Boise Cascade operation. At the monitoring site north of the latter source, much lower H_2S levels were found. From August to December, the criterion was exceeded 113 times and the maximum hourly value was 116 ppb. Virtually all measured H_2S was ascribed to emissions from Boise Cascade.

INTRODUCTION

In 1972, air quality assessment investigations were initiated in Fort Frances in response to complaints from local residents concerning alleged air pollution damage to vegetation caused by emissions from a newly constructed 500 ton-per-day bleached kraft pulp mill. An Ontario Ministry of the Environment report (1) summarized the history of this situation and presented data collected up to 1975.

Further expansion of the Ministry's assessment programme was undertaken in 1976. New features included continuous hydrogen sulphide monitoring at two locations, regular suspended particulate sampling at the same two sites and an experimental survey in which small quantities of sphagnum moss were exposed at a number of locations in the Fort Frances - International Falls area. The principal industrial air pollution sources of concern during these investigations ? was a kraft pulp mill operated by the Ontario-Minnesota Pulp and Paper Company Limited in Fort Frances and a similar facility, about 650 m (metres) west in International Falls, Minnesota, owned by Boise Cascade Corporation.

VEGETATION ASSESSMENT

(a) Vegetation Injury and Sampling

Manitoba maple (*Acer negundo*) was selected in 1973 as the most suitable of the commonly occurring Fort Frances tree species as an indicator of local air pollution injury to vegetation. On the basis of injury symptoms on Manitoba maple foliage, the 1976 injury zone was determined to be about 8 ha (hectares) comprising an inner area of 2.1 ha of moderate to severe damage close to the north side of the Fort Frances mill and an outer zone of 5.6 ha containing tree foliage with trace to light injury (Figure 1b). The total area affected was much smaller than that mapped in 1974 (26 ha) or 1975 (20 ha), indicating that a significant improvement had occurred with respect to vegetation damage near the mill. In contrast to 1974 and 1975, no visible injury attributable to kraft mill emissions was found on any vegetation to the north or southeast of Boise Cascade. In the moderate to severe injury zone, along Nelson Street, foliar injury symptoms were confined mainly to trees (Manitoba maple, basswood) and shrubs (honeysuckle), with little effect on flowers and vegetables in residential gardens. Three complaints of air pollution injury to garden vegetation were received from local residents during the 1976 growing season, but investigation of these revealed that assorted insect and disease problems were the cause of damage in all cases. Except for possible stunting, vegetable gardens on Nelson Street were in better condition in August than in the same month of any of the four preceding years. Perennial vegetation, however, continued to display symptoms of dieback resulting from the cumulative effects of pollution damage over several seasons of exposure. The effects of insect defoliator activity, which were very evident in the 1972 to 1975 period, were also much reduced in 1976.

In August, triplicate samples, each comprising 500 g (grams) of fresh leaf material, were collected from Manitoba maple trees at 26 sites in Fort Frances and six in International Falls (Figure 2). Controls were obtained from two sites in the outskirts of Fort Frances, about 4 km from the two kraft mills. All samples were analysed for chloride and sodium content. Chemical analysis results appear in Table 1, with comparable values for 1975. Sodium values are also plotted in Figure 3. Sodium concentrations near the Fort Frances mill were about the same in 1975 and 1976, despite a decrease in visible vegetation injury, and a gradient of decreasing sodium concentration with increasing distance from source was still apparent. Chloride levels were also generally similar for both years, except for a decline in 1976 at three sites just north of the Canadian mill. At the sampling locations immediately north and southeast of Boise Cascade (sites 23, 27 and 29) there was a very significant decrease in foliar sodium content, possibly reflecting benefits of a new recovery furnace brought into operation at the U.S. mill in the early part of the year. In comparing chemical analysis results for three years (1974-76, Table 2), site 23 also demonstrates the most marked improvement in 1976.

Ministry investigations since 1972 have not yet completely defined all causes of vegetation injury in Fort Frances - International Falls. Upset conditions at the Fort Frances mill, particularly in 1972 and 1974, demonstrated that atmospheric emissions of chlorine and black liquor were both damaging to nearby vegetation. Recent experiments (2) have also shown that sodium sulphate (saltcake) may also be toxic to garden vegetables, but only at concentrations well above those expected near the Fort Frances mill. The authors of the saltcake application experiment suggested that toxic effects, near kraft mills, might arise through salt accumulation in soil with subsequent uptake by plants, rather than by direct foliar injury.

(b) Moss Bag Exposure

Mosses have been found to be effective substrates for the absorption and retention of airborne contaminants (3) and techniques have been developed in which small quantities of moss have been suspended in bags at strategic locations to monitor the atmospheric environment (4). In an experimental survey, bags of *Sphagnum* moss were exposed for two, one-month periods in July and August, 1976, at 32 sites in Fort Frances and International Falls. Exposure sites are shown in Figure 4. Each sample consisted of 3 g of oven-dried moss in a 10 x 20 cm envelope of fibreglass screening which was attached with adhesive tape to a supporting structure about 2.5 m above ground level. Prior to enclosure in the envelope, the moss was washed with 0.5 molar nitric acid to strip away any contaminants present and to increase the ion exchange capacity thus encouraging a higher rate of contaminant deposition and retention.

Both sets of samples were submitted for analysis of calcium, chloride and sodium content, results of which appear in Table 3. In contrast to vegetation, sodium levels in moss did not provide any evidence of decreasing concentrations with distance from source, and values for controls were as high as those at several sites near both pulp mills. Calcium and chloride results, however, indicated the presence of airborne calcium and chloride contamination north and east of the Fort Frances mill (Figures 5 and 6). Values for the August exposure were generally higher than those for July, especially for chloride. Chloride levels in moss and Manitoba maple foliage were of the same order of magnitude. For airborne calcium, moss proved to be a much better indicator than Manitoba maple foliage. Results from surveys in 1973 and 1974 had shown that Manitoba maple leaves contained too high a natural background calcium level to permit detection of additional deposition of airborne calcium.

SNOW SAMPLING

Results from snow sampling surveys conducted in 1974 and 1975 have been discussed in detail in earlier reports (1). The principal finding was that zones of elevated calcium, chloride, sodium and sulphate occurred as a result of contaminant fallout from the two kraft mills. Visible particulate matter, such as sawdust, bark char and saltcake, could also be identified on and below the snow surface at points close to emission sources. Sampling conducted in late 1975, when the Fort Frances mill was closed by strike, showed marked reductions in calcium, sodium and sulphate in snow in the area near the Canadian plant, while contaminant levels ascribed to Boise Cascade operations were the same, or greater, than before.

Due to continuation of the strike into March, no samples were collected in 1976. A survey was conducted, however, by the Ontario-Minnesota Pulp and Paper Company on March 16, about 10 days after mill operations resumed. Their results showed snow concentrations of sodium and sulphate to be generally lower than those found by Ministry of Environment during the strike period. Calcium levels were about the same. Differences in results were possibly due to differences in sampling method, site selection criteria and/or snow conditions.

Snow sampling surveys are useful as indicators of the kind, amount and extent of contaminants in snow attributable to airborne sources. Although elevated quantities of calcium, chloride, sodium and sulphate have been found in snow near the pulp mills in Fort Frances and International Falls, the adverse environmental effects, if any, of the presence of these substances in snow has not yet been established.

Based on investigations in the vicinity of several kraft pulp mills in northern Ontario, guidelines have been established for levels of kraft mill contaminants in snow meltwater. Concentrations above 5 ppm (parts per million) for calcium, 5 ppm for chloride, 10 ppm for sodium and 10 ppm for sulphate are considered excessive. Values above these guidelines have occurred regularly in the Fort Frances - International Falls area.

AIR MONITORING

(a) Dustfall

Dustfall, one of the most visible classes of air pollutants, comprises particulate matter which settles out from the atmosphere under the influence of gravity. It was measured by exposing open-top vessels for 30 days and weighing the collected matter. Results were expressed in tons per square mile per month. The soluble fraction of dustfall was also analysed for soluble sulphate, with results expressed in the same units used for total dustfall.

Monitoring sites for dustfall (and sulphation) are shown in Figure 7. Monthly results for total dustfall and soluble sulphate in dustfall are summarized in Table 4. The annual averages for six of the seven sites are plotted in Figure 8. Results indicated that, in 1976, dustfall regularly exceeded the Ontario criterion at the four stations closest to the Ontario-Minnesota mill. Low levels were recorded at the control site (station 62037) and at the cemetery location (station 62032). The latter finding suggested that no significant quantities of particulate matter were deposited in Fort Frances as a result of operations at Boise Cascade. Soluble sulphate accounted for about 10 to 15 percent of total dustfall. Assuming that all sulphate in dustfall was soluble and that its presence was in the form of sodium sulphate, then sodium sulphate (saltcake) comprised about 20 percent of total dustfall. Other possible contributors to total dustfall might have included other sodium and calcium salts from the mill's recovery furnace and lime kiln operations, sawdust, and re-entrainment of ground level dust. Sawdust was noted from time to time in dustfall jars at the Nelson, Church and Sinclair Street sites (stations 62033, 62030 and 62036, respectively), but its quantity was not determined. Black particulate matter, frequently observed in 1975 and attributed to the Boise Cascade mill, was virtually absent in 1976.

Dustfall levels during January and February (strike months) were much lower than in other months of the year. The effects of the Fort Frances mill operations on local dustfall are clearly shown by data in Table 5 which compares two, 4-month periods, one representing the situation under normal mill operations and the other a period during mill closure. For the four stations closest to the mill, average dustfall was 25 tons during normal operations and 10 tons during the strike, a decrease of 60 percent. The decrease for all sites was just under 50 percent.

The Ontario-Minnesota Pulp and Paper Company conducted dustfall measurements at several locations in November, 1976. Their data were in general agreement with those of Ministry of the Environment in that they found a clear gradient of decreasing dustfall with increasing distance from their mill.

(b) Suspended Particulate

Suspended particulate constitutes particulate matter of small size which remains in the atmosphere for extended periods. A measured volume of air was drawn through pre-weighed glass fibre filters for 24-hour periods every sixth day and the filters were then re-weighed to determine the quantity of dust collected. Results were expressed in micrograms per cubic metre of air ($\mu g/m^3$).

Results for 1976 appear in Table 6, together with prevailing wind for sampling dates. Station 62032, in operation the full year, had only two values above the 24-hour criterion of 120 $\mu g/m^3$. The annual geometric mean, 40 $\mu g/m^3$, was well within the Ontario criterion of 60. A less satisfactory situation was recorded at station 62030, near the Town Hall. Here, during a 5-month period, the daily criterion was exceeded six times and the geometric mean was 79 $\mu g/m^3$. At both stations, highest average suspended particulate concentrations were found with southerly prevailing winds (south-southeast to southwest), suggesting that both mills were sources of suspended particulate emissions.

(c) Sulphation Rates

Sulphation rate was measured by exposing small plastic plates coated with lead dioxide to the atmosphere for 30-day periods. Lead dioxide reacted with gaseous sulphur compounds in the air to form lead sulphate. The amount of sulphate formed was analytically determined and results reported as milligrams of sulphur trioxide per hundred square centimetres per day (mg $SO_3/100\ cm^2$/day). Sulphation plates are normally used as sulphur dioxide detectors but, because of lead dioxide's oxidizing power, other reactive sulphur compounds like hydrogen sulphide and mercaptans can also be converted to sulphate. In Fort Frances, where sulphur dioxide concentrations are very low (1), sulphation plates have been used to detect hydrogen sulphide and other organic sulphide compounds.

In 1976, sulphation rates were highest at the monitoring point closest to the Fort Frances kraft mill (Table 7, Figure 9). For the 7-station network, average rates were slightly higher in 1976 than 1975. During the strike (mid October, 1975 to early March, 1976), average sulphation rates were similar to those found in the same period in late 1974 - early 1975 when the Fort Frances mill was operating.

(d) Hydrogen Sulphide

A number of organic sulphur compounds are commonly emitted to the atmosphere by kraft pulp mills. Hydrogen sulphide (H_2S) and methyl mercaptan (CH_3SH) are the principal contaminants in this group. Both are unpleasant smelling gases at very low concentrations. At higher levels, lead-based paints may be blackened, vegetation may be injured and respiratory irritation may be experienced by human population.

During 1976, hydrogen sulphide levels were monitored at station 62030, starting in late January, and at station 62032, beginning in early August. Measurements were made with Philips PW 9700 series continuous analysers, which operated on the principle of continuous coulometric titration. All pollutants except H_2S and mercaptans were removed by a scrubbing device from sample air before it entered the instrument. The measurement range used in Fort Frances varied from 0-200 ppb (parts per billion) to 0-800 ppb, depending on the maximum H_2S concentrations expected or encountered. On the smaller scale, the detection limit was about 2 ppb.

A summary of H_2S data for the two Fort Frances stations is contained in Table 8. Valid data were collected 84 percent of the time at both stations. Calibration periods, power failures and instrument malfunction accounted for the other 16 percent of the total monitoring period. At station 62030, near the Town Hall, measurable quantities of H_2S were detected about 46 percent of the time. Concentrations above the Ontario hourly criterion (20 ppb) occurred on 1071 occasions, or about 14 percent of the time. The maximum hourly value recorded was 458 ppb, more than 22 times greater than the criterion. Off-scale peaks (>800 ppb) were sometimes noted, but these rarely lasted more than a few minutes on each occasion. Lowest values occurred in February, when the Ontario-Minnesota mill was not operating. The frequency of high concentrations decreased significantly in December, indicating benefits from additional emission control devices installed at that time.

H_2S levels were generally much lower at station 62032 in the cemetery to the north of Boise Cascade. Concentrations above detection limit were recorded 21 percent of the time and above criterion levels occurred during 113 hours, or 4 percent of the time. The highest frequency of above criterion values was measured in August, but winds favouring fumigations occurred more often in this month than in following months (Table 11).

The association between above criterion H_2S levels and wind direction was also investigated. Data for station 62030 are reported in Table 9 and for station 62032 in Table 10. The same results are shown in the form of pollution roses in Figures 10 and 11. At station 62030, 57 percent of the above criterion values occurred when directly downwind of the Fort Frances mill (140-170°) and 14 percent were recorded downwind of Boise Cascade (240-260°). If the concentrations for the direction intermediate between the two mills, 230°, were divided equally between the two sources, then 61 percent of the values exceeding 20 ppb could be ascribed to Ontario-Minnesota emissions and 18 percent to Boise Cascade. Finally, if H_2S levels recorded during calms were allocated two thirds to Ontario-Minnesota and one third to Boise Cascade, then 70 percent of all values would be attributable to Ontario-Minnesota operations and 22 percent to the U.S. mill. The other 8 percent of high values could not be definitely related to specific sources.

For station 62032, H_2S associated with wind directions from Boise Cascade (140-170°) accounted for 67 percent of all observations above 20 ppb. Only 4 percent could be related to wind from the Fort Frances mill (110-120°). If H_2S recorded during calms and for wind directions 130° and 180° were also added to those for the 140-170° sector, then about 88 percent of values above the 20 ppb criterion would be accounted for by Boise Cascade emissions. Eight percent of concentrations above 20 ppb could not be source oriented.

In early April, Boise Cascade began operating a new recovery furnace. Although station 62030 was downwind of Boise Cascade about 13 percent of the time during the two months preceding April, no significant differences in average H_2S levels were observed between downwind conditions in February-March and those for the remainder of the year.

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- Utility Operations Section, Northwestern Region, Ministry of the Environment, and Fort Frances Field Office, Ministry of Industry and Tourism, for assistance in the operation of the air monitoring network.
- Air Quality and Meteorology Section, Air Resources Branch, for analysing and summarizing H_2S data.
- Air Quality Laboratory Section, Laboratory Services Branch, for chemical analysis of vegetation and for the preparation and analysis of sulphation plates.
- Regional Laboratory, Northwestern Region, for determination of dustfall weight and sulphate in dustfall, and for determination of suspended particulate weights.
- Phytotoxicology Section, Air Resources Branch, for processing vegetation samples.

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3. Goodman, G. T. and Roberts, T. M. (1971). Plants and soils as indicators of metals in the air. Nature 231:287-292.
4. Little, P. and Martin, M. H. (1974). Biological monitoring of heavy metal pollution. Environ. Pollut. 6:1-19.

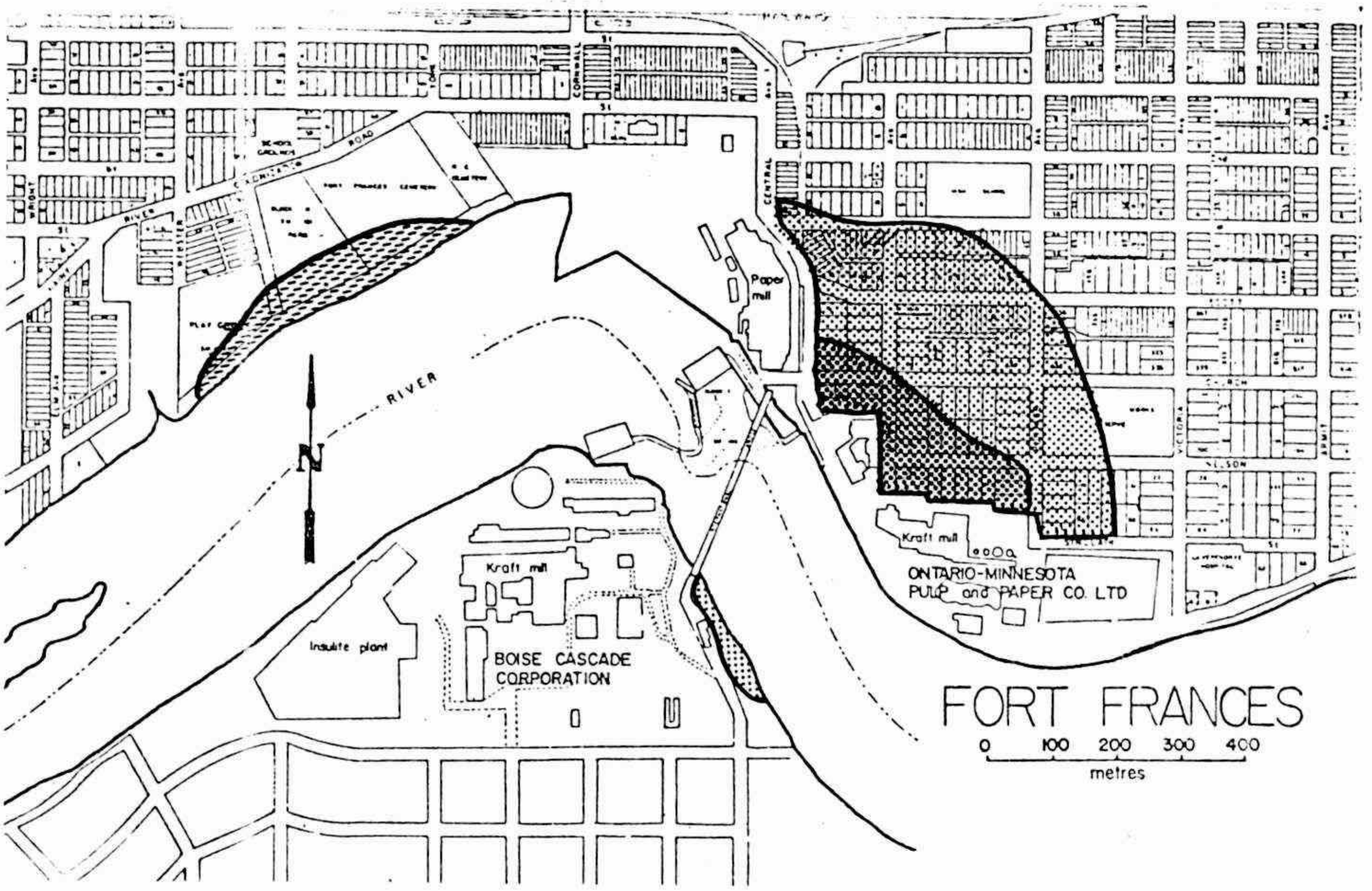

Figure la. Vegetation injury, 1975.

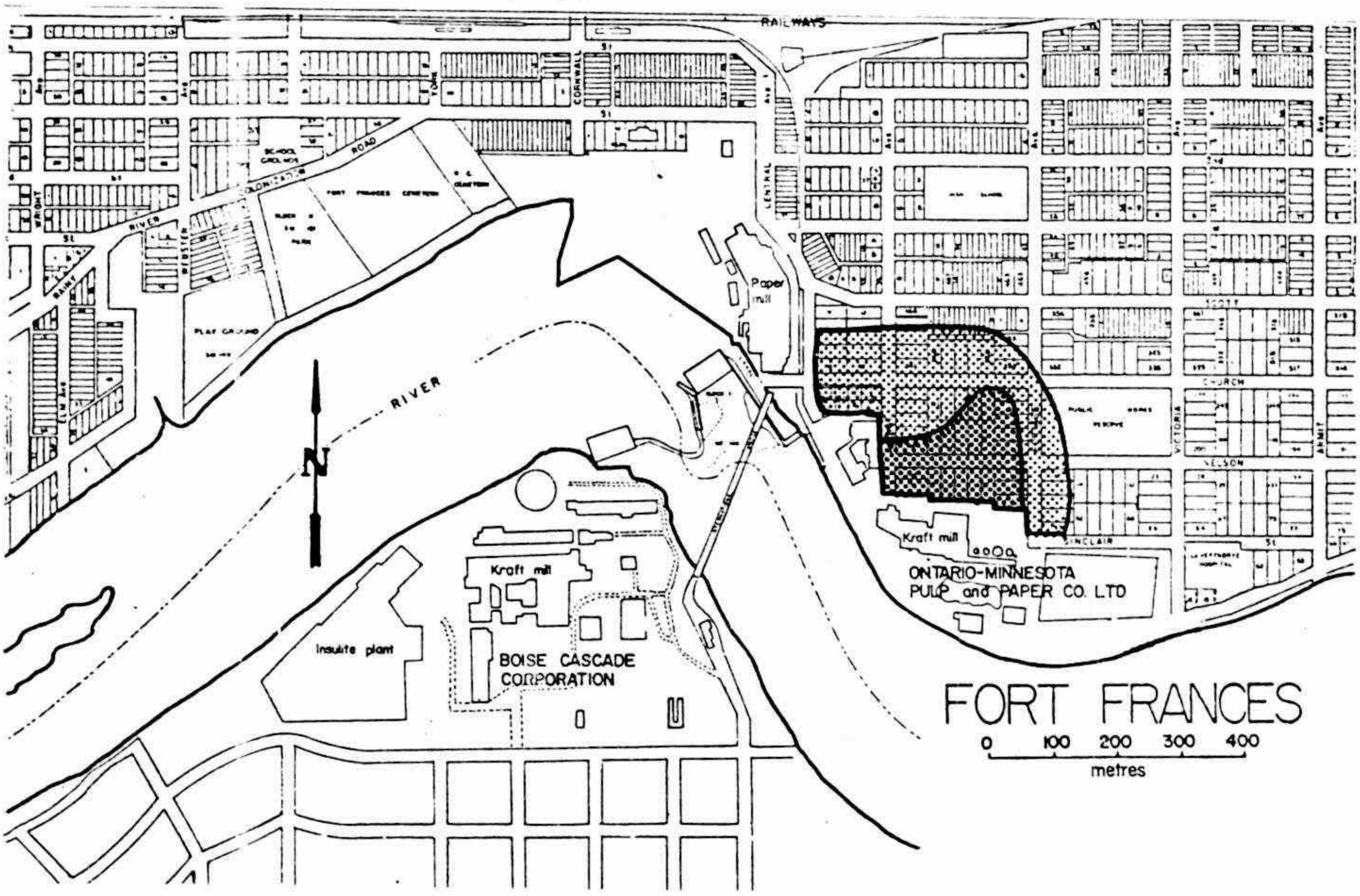

Figure lb. Vegetation injury, 1976.

▩ Moderate to severe (16-35, >35% leaf area affected)

▨ Trace to moderate (0-5, 6-15, 16-35% leaf area affected)

░ Trace to light (0-5, 6-15% leaf area affected)

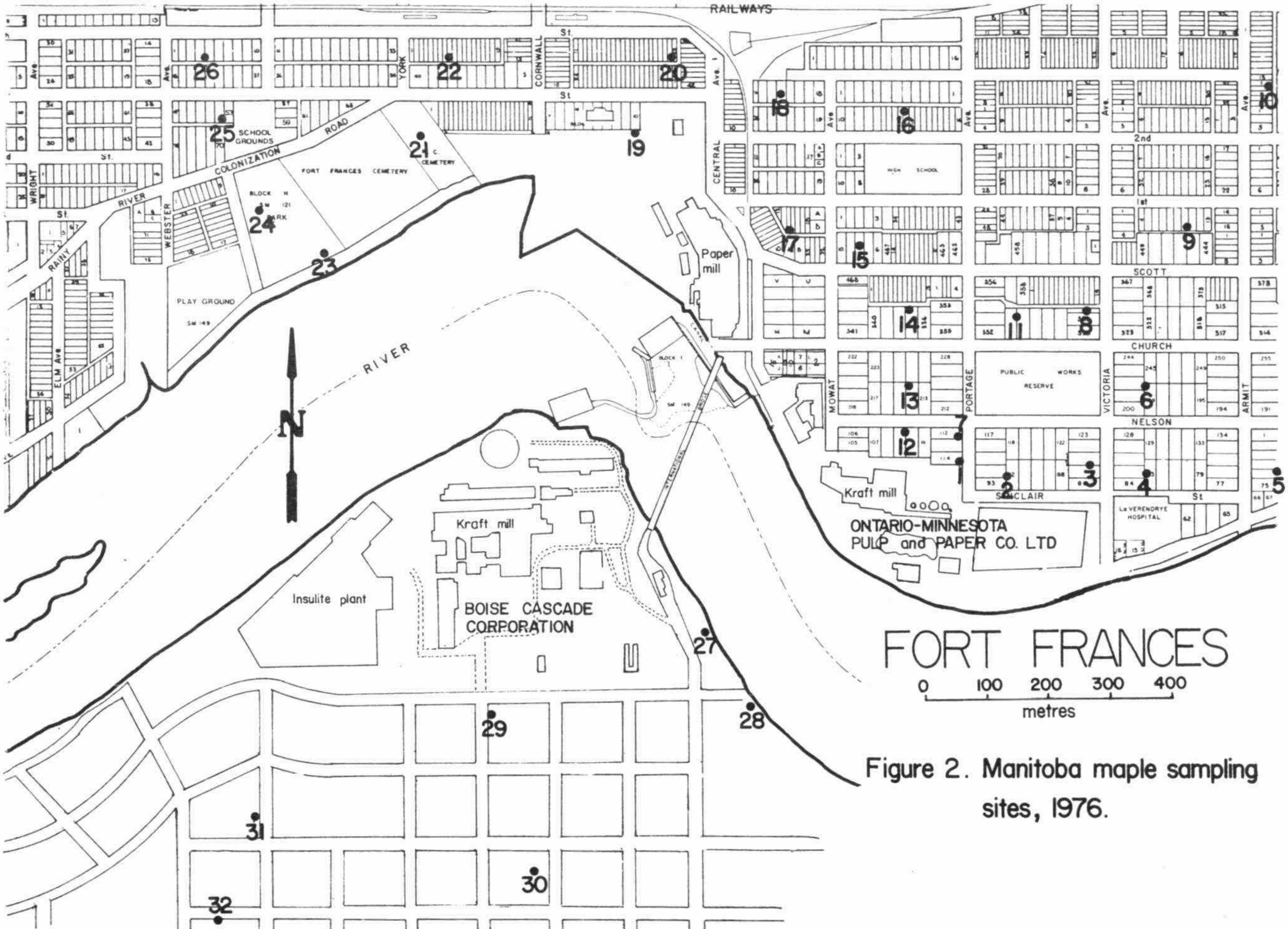

Figure 2. Manitoba maple sampling sites, 1976.

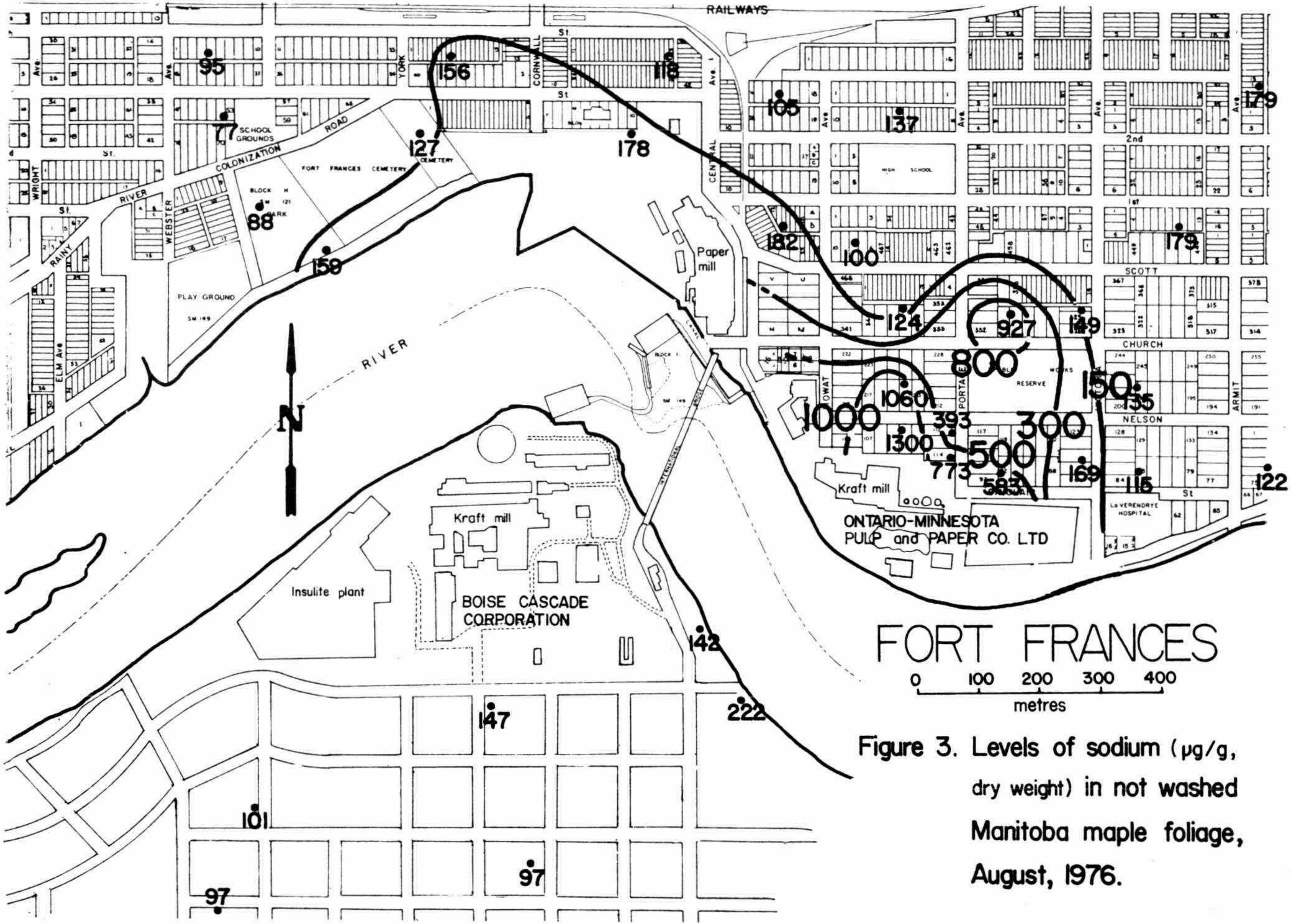

Figure 3. Levels of sodium (μg/g, dry weight) in not washed Manitoba maple foliage, August, 1976.

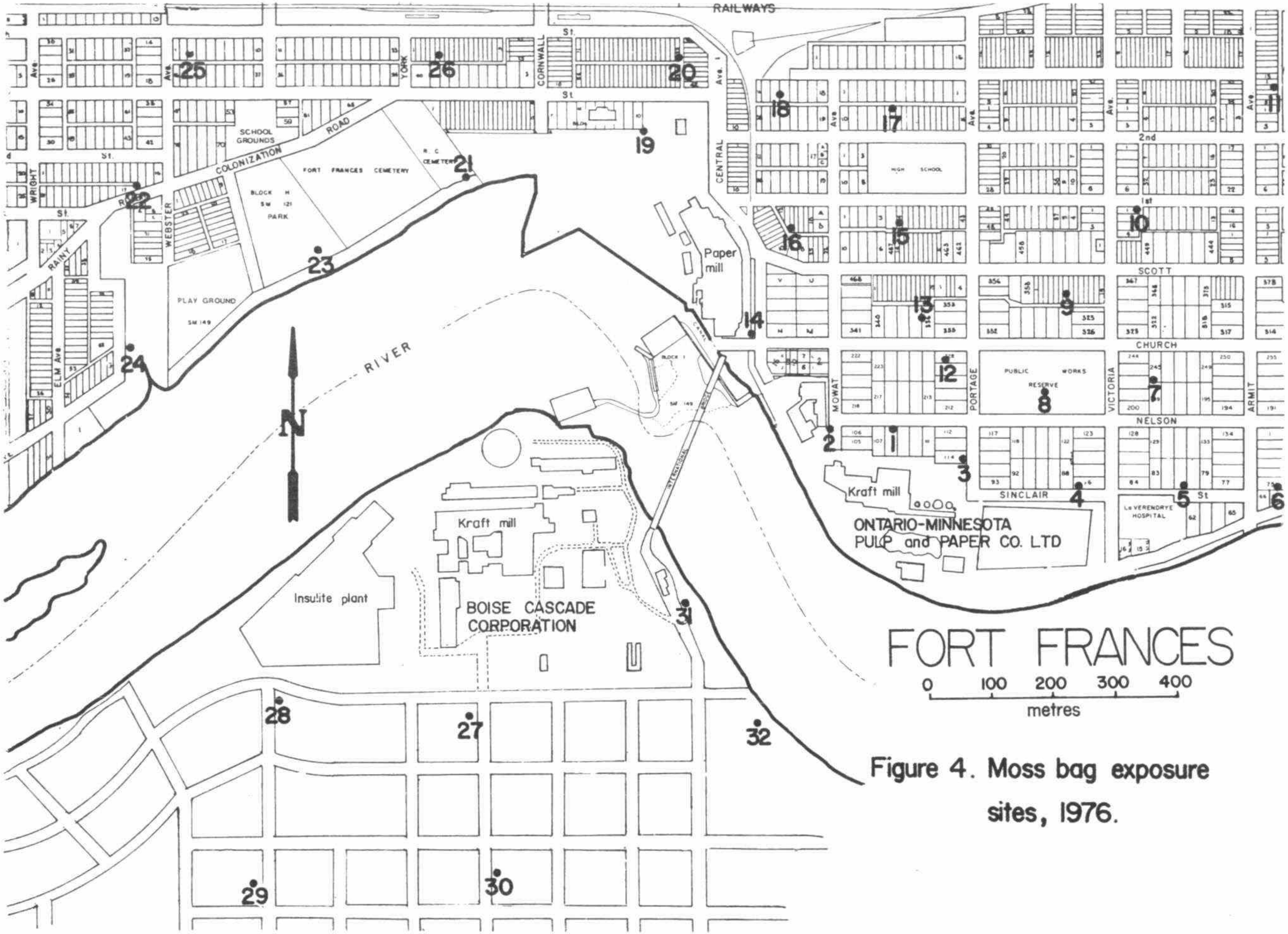

Figure 4. Moss bag exposure sites, 1976.

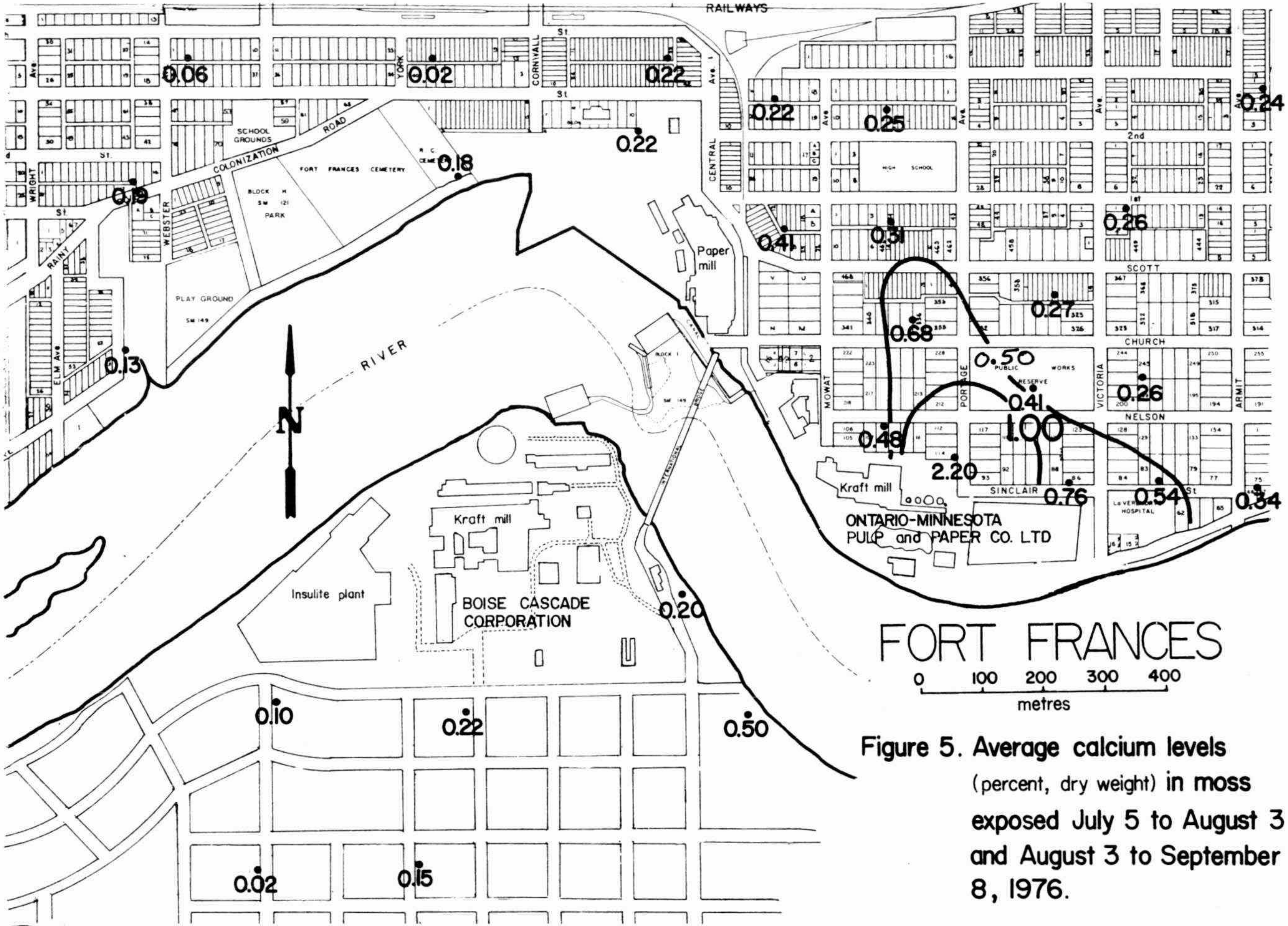

Figure 5. Average calcium levels (percent, dry weight) in moss exposed July 5 to August 3 and August 3 to September 8, 1976.

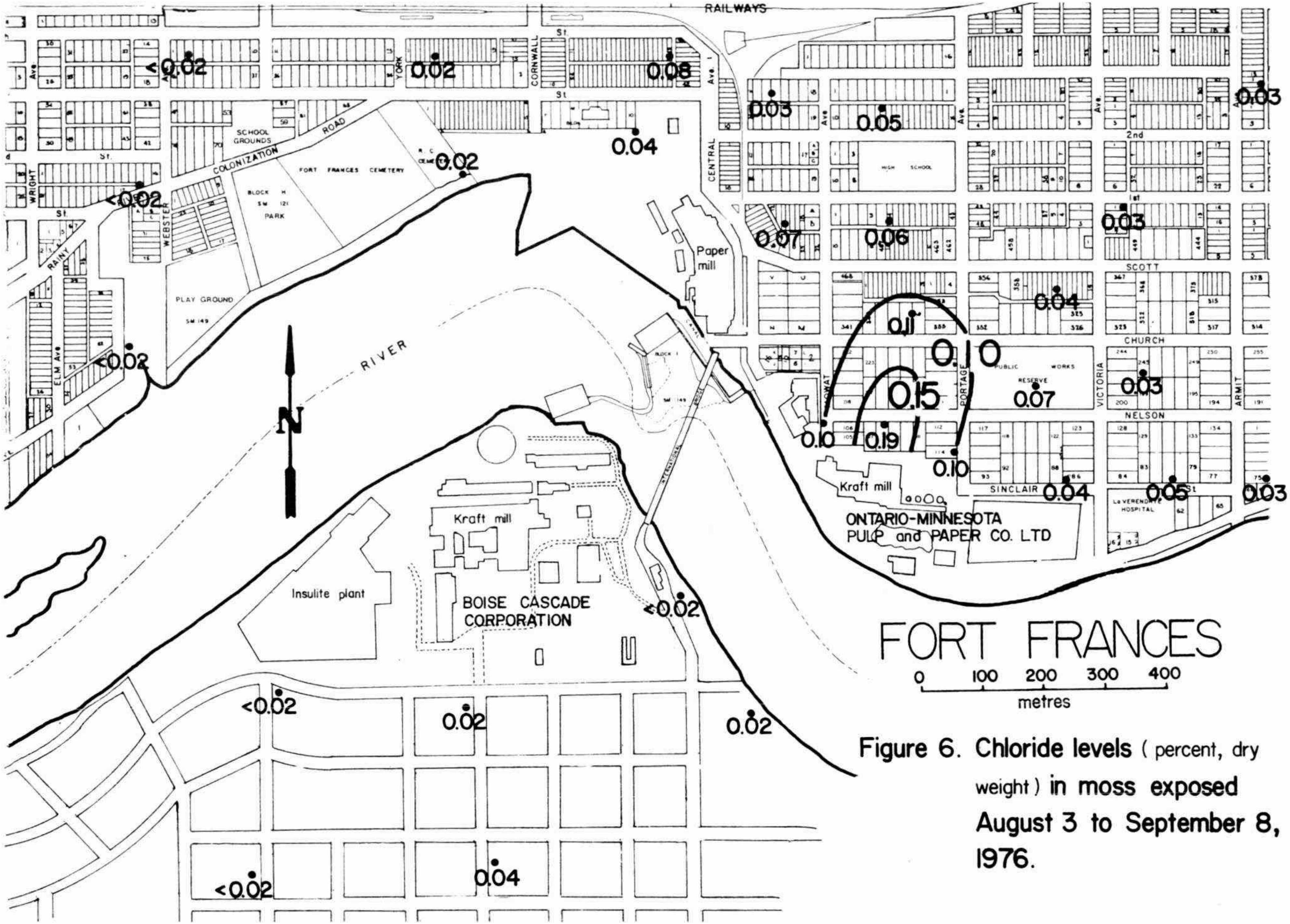

Figure 6. Chloride levels (percent, dry weight) in moss exposed August 3 to September 8, 1976.

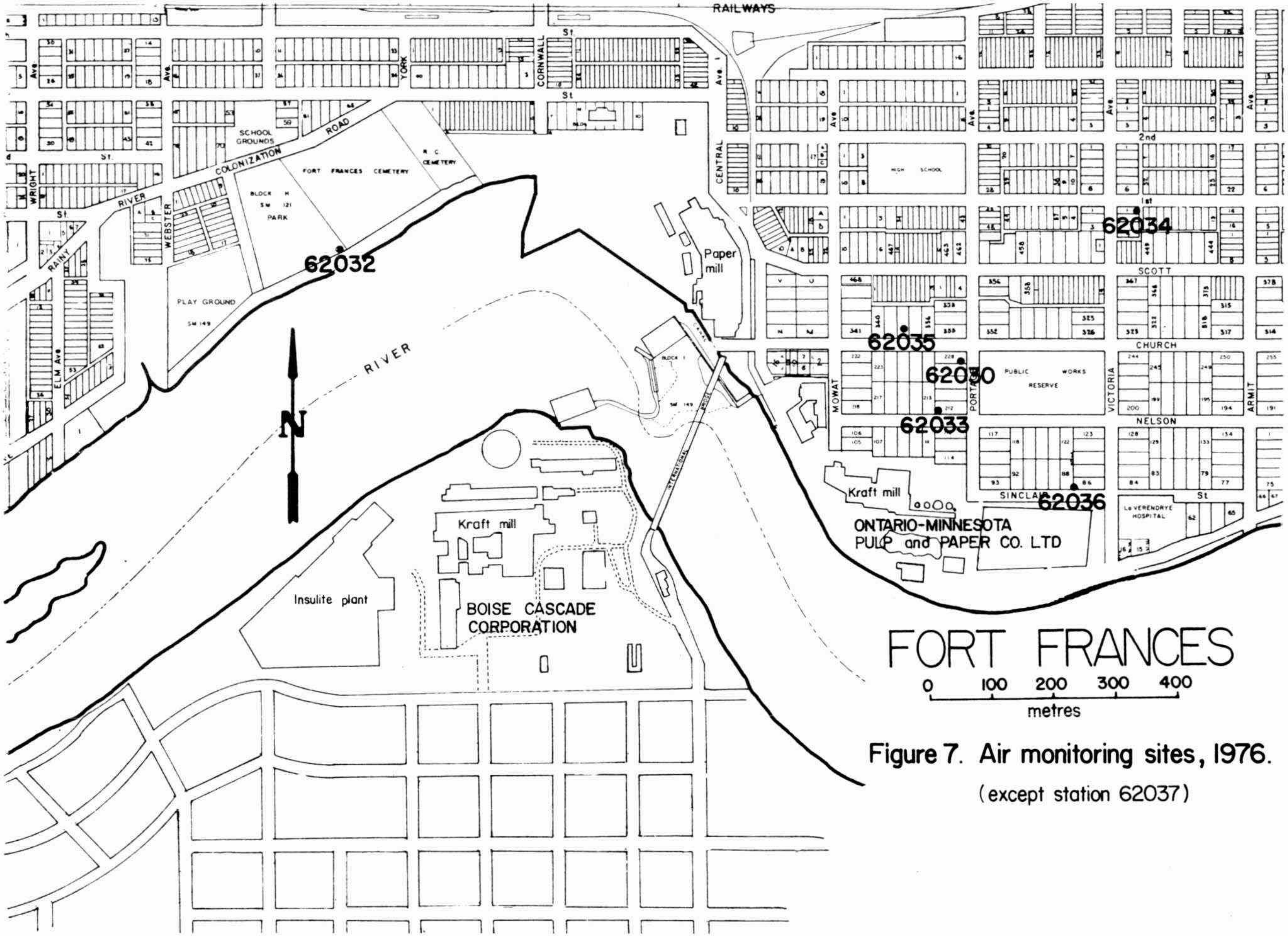

Figure 7. Air monitoring sites, 1976.

(except station 62037)

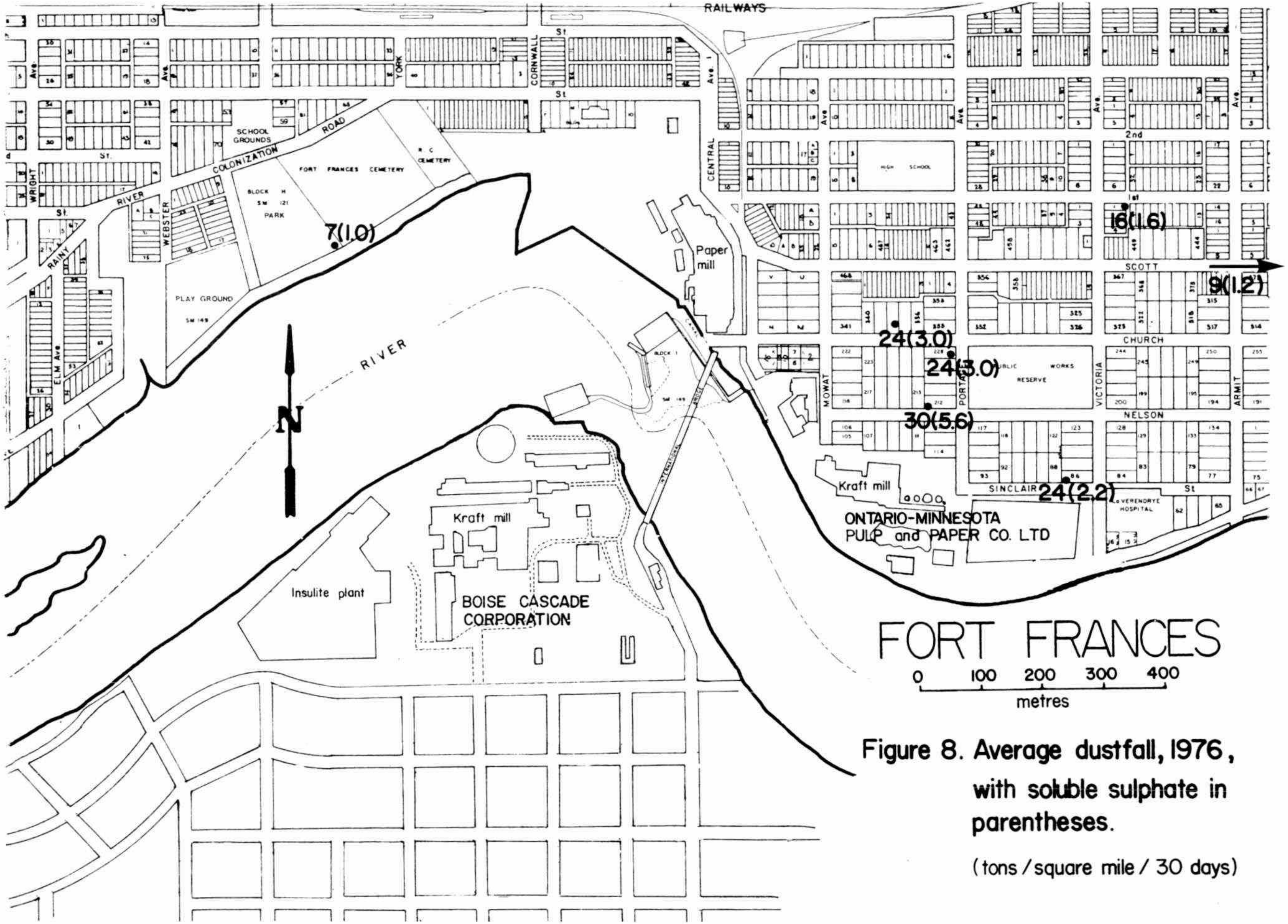

Figure 8. Average dustfall, 1976, with soluble sulphate in parentheses.

(tons / square mile / 30 days)

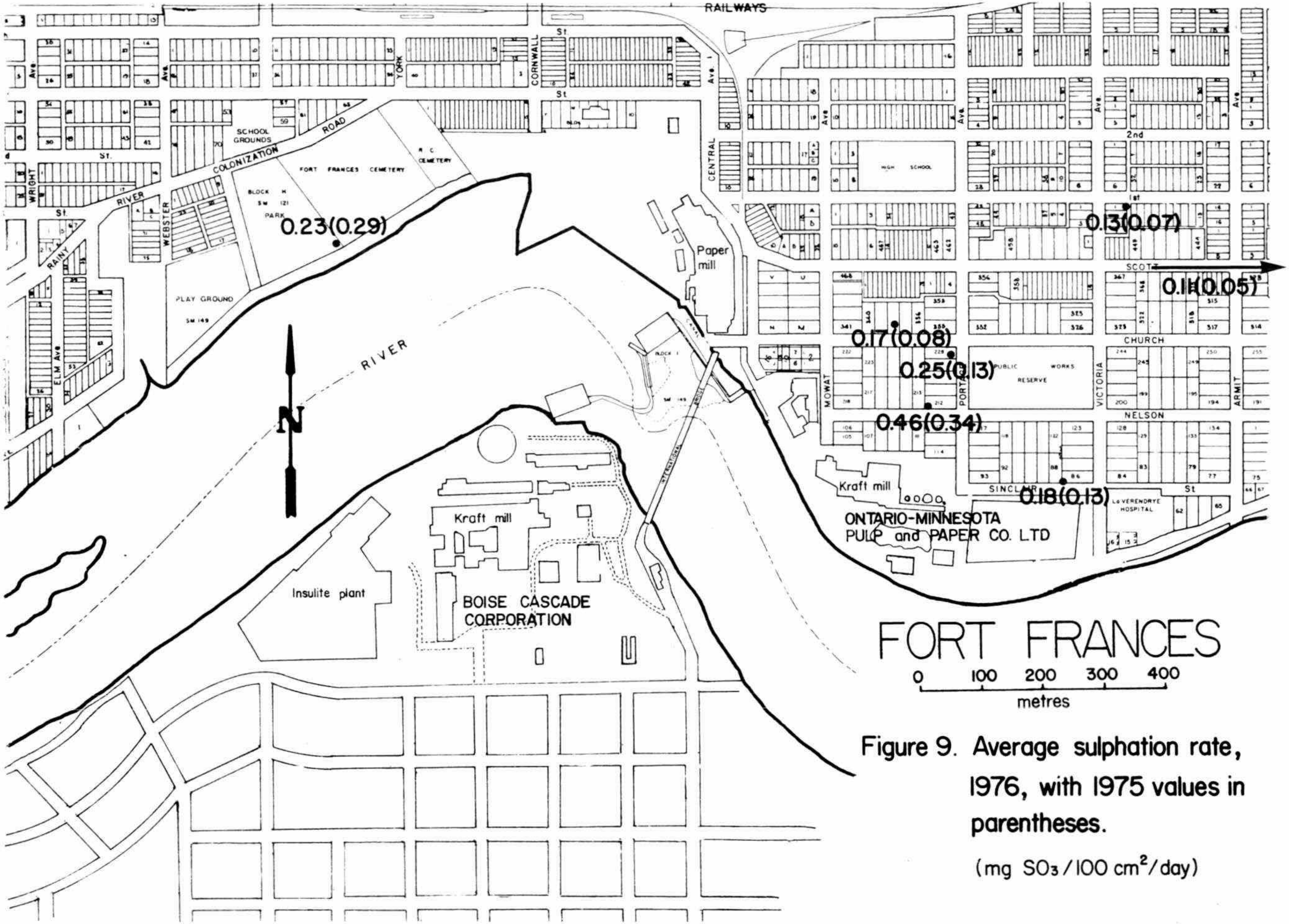

Figure 9. Average sulphation rate, 1976, with 1975 values in parentheses.

(mg $SO_3/100\ cm^2/day$)

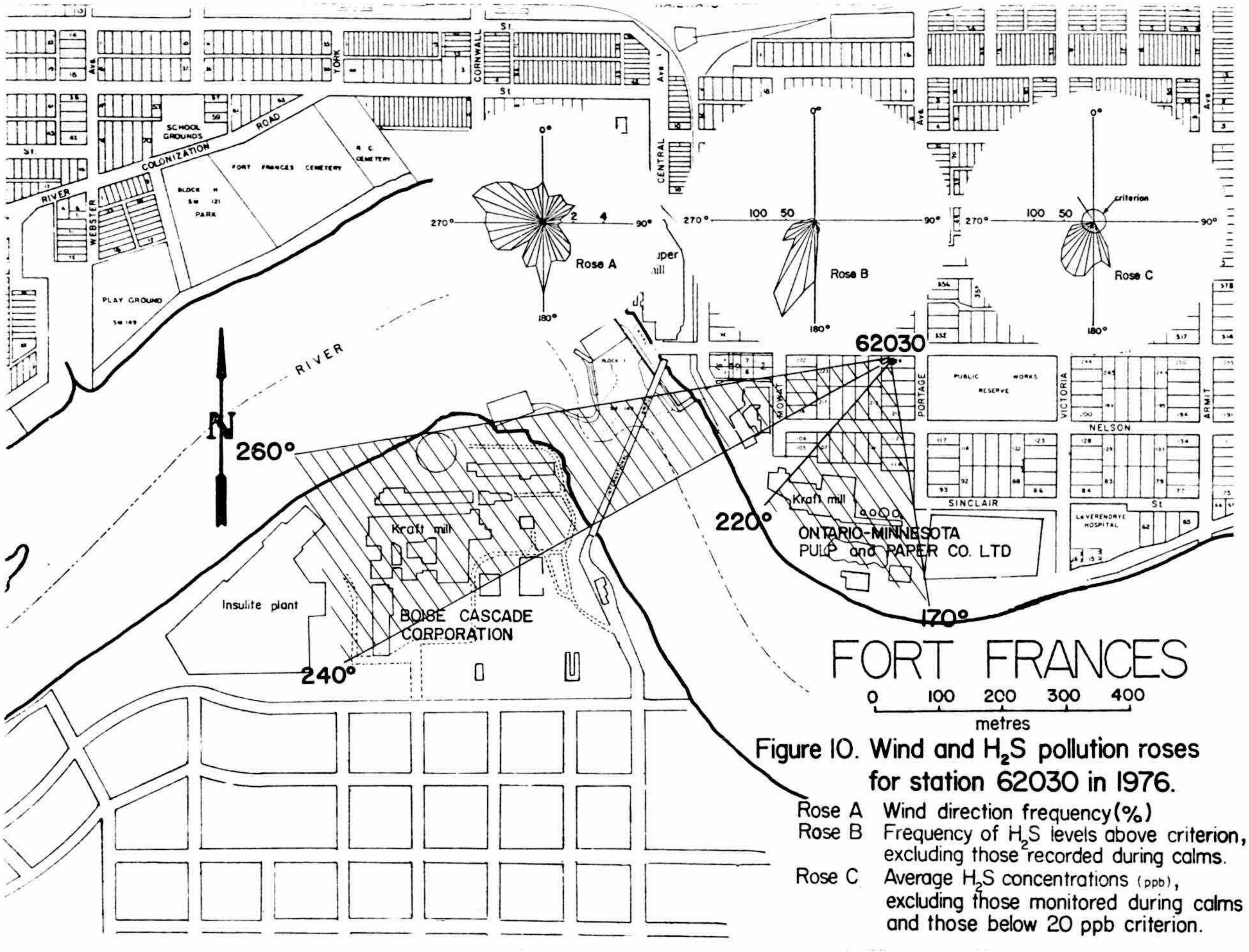

Figure 10. Wind and H_2S pollution roses for station 62030 in 1976.

Rose A Wind direction frequency (%)

Rose B Frequency of H_2S levels above criterion, excluding those recorded during calms.

Rose C Average H_2S concentrations (ppb), excluding those monitored during calms and those below 20 ppb criterion.

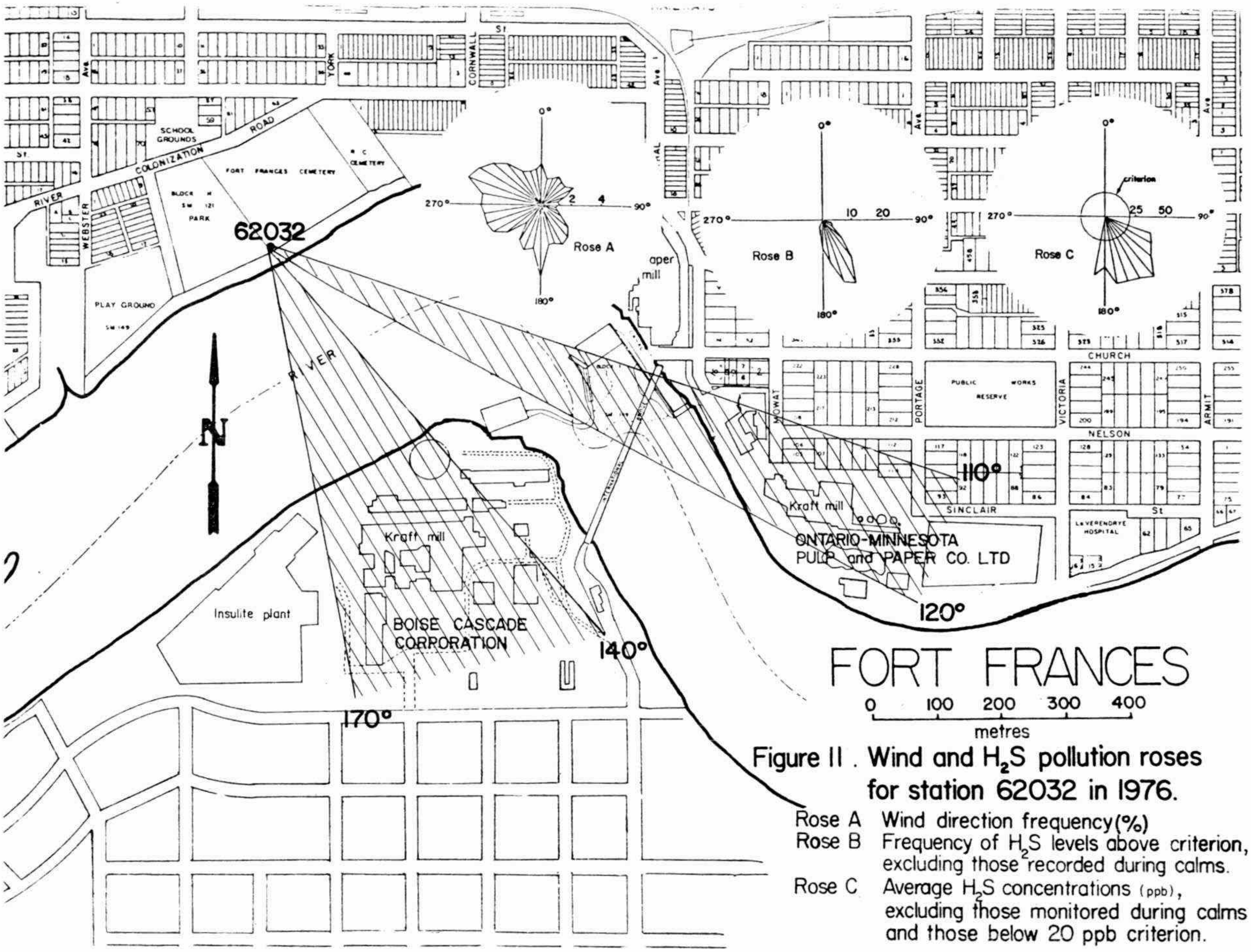

Figure II . Wind and H_2S pollution roses for station 62032 in 1976.

Rose A Wind direction frequency(%)
Rose B Frequency of H_2S levels above criterion, excluding those recorded during calms.
Rose C Average H_2S concentrations (ppb), excluding those monitored during calms and those below 20 ppb criterion.

TABLE 1. Sodium (ppm, dry weight) and chloride (percent, dry weight) in not washed Manitoba maple foliage, Fort Frances-International Falls, 1975 and 1976.

Site	Distance(metres) and direction from source*	Sodium		Chloride	
		1975**	1976	1975	1976
1	95 E	537	773	.26	.29
2	180 E	327	583	.09	.14
3	320 E	253	169	.07	.13
4	425 E	225	115	.06	.08
5	630 E	198	122	.18	.14
6	440 ENE	176	135	.12	.11
7	110 E	640	393	.22	.15
8	410 NE	192	149	.13	.12
9	620 NE	176	179	.12	.16
10	885 NE	131	179	.08	.10
11	325 NNE	313	927	.13	.12
12	75 N	1473	1300	.36	.16
13	145 N	459	1060	.37	.16
14	270 N	399	124	.33	.14
15	400 N	317	100	.08	.09
16	600 N	496	137	.15	.14
17	445 NNW	371	182	.11	.13
18	650 NNW	507	105	.10	.13
19	890 NNE	347	178	.08	.10
20	1030 NNE	314	118	.11	.11
21	770 N	559	127	.07	.08
22	920 N	718	156	.10	.10
23	580 NNW	1516	159	.04	.03
24	690 NNW	396	88	.04	.05
25	840 NNW	364	77	.09	.12
26	940 NNW	272	95	.10	.11
27	400 ESE	1033	142	.13	.12
28	625 ESE	311	222	.13	.17
29	280 SSE	705	147	.05	.08
30	550 S	179	97	.05	.07
31	425 SW	283	101	.10	.07
32	700 SSW	168	97	.03	.06
Control	3980 WSW	50	43	.04	.06
Control	4050 NE	89	114	.03	.04

*Source arbitrarily designated as Ontario-Minnesota recovery furnace stack for stations 1-18 plus controls, and Boise Cascade recovery furnace stack for stations 19-32.

**1975 values represent averages of three sets of triplicate samples collected in June, July and August. Data for 1976 are based on one set of triplicate samples collected in August.

TABLE 2. Comparison between concentrations of sodium and chloride in not washed Manitoba maple foliage, Fort Frances in 1974, 1975 and 1976.

	Sodium (ppm, dry weight)			Chloride (percent, dry weight)		
Site	1974	1975	1976	1974	1975	1976
1	890	537	773	.32	.26	.29
2	619	327	583	.18	.09	.14
4	522	225	115	.07	.06	.08
5	449	198	122	.19	.18	.14
7	482	640	393	.26	.16	.15
8	222	192	149	.15	.11	.12
9	214	176	179	.10	.10	.16
13	503	459	1060	.18	.26	.16
15	377	317	100	.16	.08	.09
18	315	507	105	.07	.07	.13
23	1803	1516	159	.04	.05	.03
Control	88	50	43	.05	.04	.06
Control	59	89	114	.05	.03	.04

TABLE 3. Concentrations of calcium, chloride and sodium in moss in bags exposed during July-September, 1976, in Fort Frances - International Falls.

Site	Distance(metres) and direction from source*	Calcium(%)		Chloride(%)		Sodium(ppm)	
		Jul-Aug	Aug-Sep	Jul-Aug	Aug-Sep	Jul-Aug	Aug-Sep
1	75 NNW	.75	.21	.03	.19	1000	700
2	140 WNW	-	.41	-	.10	-	570
3	110 ENE	2.00	2.40	<.02	.10	170	670
4	280 E	.31	1.22	<.02	.04	300	500
5	460 E	.18	.90	<.02	.05	270	570
6	620 E	.03	.66	<.02	.03	80	450
7	430 ENE	.11	.41	<.02	.03	90	430
8	260 ENE	.12	.70	<.02	.07	70	480
9	390 NE	.13	.38	<.02	.04	80	350
10	570 NE	.09	.44	<.02	.03	90	400
11	1110 NE	-	.48	-	.03	-	520
12	210 NNE	-	.51	-	.06	-	600
13	270 N	.37	1.00	<.02	.11	160	680
14	340 NW	-	.72	-	.07	-	580
15	410 N	.17	.45	<.02	.06	200	490
16	440 WNW	.12	.70	<.02	.07	140	610
17	595 N	.08	.42	<.02	.05	140	580
18	645 NNW	.06	.37	<.02	.03	130	470
19	625 NE	.03	.41	<.02	.04	70	430
20	750 NE	.07	.37	<.02	.08	100	360
21	465 N	.10	.25	<.02	.02	470	460
22	745 NW	.05	.33	<.02	<.02	160	300
23	405 NNW	-	-	-	-	-	-
24	550 WNW	.03	.23	<.02	<.02	110	410
25	705 NNW	-	.06	-	<.02	-	300
26	660 N	.04	.35	<.02	.02	110	380
27	405 S	.04	.40	<.02	.02	100	400
28	480 SW	.16	.04	<.02	<.02	120	240
29	725 WSW	.02	.03	<.02	<.02	130	260
30	670 S	.02	.28	<.02	.04	130	370
31	470 ESE	.19	.20	<.02	<.02	70	330
32	660 SE	.80	.20	<.02	.02	150	380
Control	3980 WSW	.02	.78	<.02	.03	130	490
Control	4050 NE	.20	.22	<.02	<.02	220	290

*Source arbitrarily designated as Ontario-Minnesota recovery boiler stack for stations 1-18 plus controls, and Boise-Cascade recovery boiler stack for stations 19-32.

TABLE 4. Total dustfall and soluble sulphate in dustfall, Fort Frances, 1976.

Station	Location	Distance(metres) and direction from source*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
			Total dustfall (tons/square mile/30 days)												
62030	Church/Portage	215 NNE	5	14	32[+]	56	-	-	23	29	23	17	21	21	24
62032	Cemetery	990 WNW	5	6	10	-	4	-	12	11	8	7	5	4	7
62033	Nelson/Portage	135 NNE	4	12	83	67	22	-	18	37	28	18	18	25	30
62034	First/Victoria	590 NE	4	13	20	22	17	-	19	19	23	15	11	10	16
62035	Legion Building	250 N	1	20	31	29	25	-	27	35	28	25	15	25	24
62036	Sinclair/Victoria	295 E	7	13	23	22	20	-	37	37	30	31	23	26	24
62037	Reid/Gillon	1385 ENE	2	7	11	-	6	-	15	14	11	12	7	5	9
			Soluble sulphate in dustfall (tons/square mile/30 days)												
62030	Church/Portage	215 NNE			-	4.2	-	-	1.7	4.2	1.3	2.1	2.0	3.4	3.0
62032	Cemetery	990 WNW			3.3	-	0.4	-	0.7	1.6	0.7	0.5	0.3	-	1.0
62033	Nelson/Portage	135 NNE			6.6	19.4	3.2	-	0.2	4.4	3.5	4.3	3.4	-	5.6
62034	First/Victoria	590 NE			3.9	1.8	0.9	-	0.5	1.9	1.6	1.0	1.0	1.8	1.6
62035	Legion Building	250 N			4.2	2.8	1.4	-	0.2	6.9	1.9	2.2	1.5	3.7	3.0
62036	Sinclair/Victoria	295 E			3.3	1.1	0.6	-	3.0	1.4	1.0	3.0	2.7	3.5	2.2
62037	Reid/Gillon	1385 ENE		1.6	1.8	-	0.1	-	1.0	1.1	0.9	1.0	1.3	1.8	1.2

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*Source arbitrarily designated as Ontario-Minnesota kraft mill recovery furnace stack.

[+] Values above criteria of 20 (monthly) or 13 (annual average) are underlined.

TABLE 5. Comparison between dustfall (tons/square mile/30 days) recorded during mill operating and non-operating conditions.

	Mill operating					Mill closed				
	1974		1975			1975		1976		
Station	Nov	Dec	Jan	Feb	Average	Nov	Dec	Jan	Feb	Average
62030	30	21	30	15	24	18	9	5	14	12
62032	9	5	5	4	6	7	6	5	6	6
62033	32	22	62	32	37	11	6	4	12	8
62034	20	9	8	8	11	12	4	4	13	8
62035	40	12	10	16	20	13	7	1	20	10
62036	21	15	23	14	18	14	6	7	13	10
62037	-	-	-	-	-	10	3	2	7	6
Averages	25	16	23	15	19	12	6	4	12	9

TABLE 6. Suspended particulate (μg/m³), stations 62030 and 62032, Fort Frances, 1976.

Date	62032 (Cemetery)	Wind*
Jan 1	9	E
7	11	WSW
13	16	W
19	16	NW
25	21	WNW
31	9	W
Feb 6	12	WSW
11	31	WNW
18	12	W
24	98	SW
Mar 1	16	ENE
7	13	WNW
13	39	SSE
19	71	ESE
25	41	ESE
31	77	NNE
Apr 6	55	N
12	52	SSW
18	-	
24	41	ENE
30	49	WNW
May 6	61	NW
12	90	SE
18	96	SSE
24	48	NE
30	103	E
Jun 5	96	S
11	138[+]	E
17	44	S
23	-	
29	51	NNE

Date	62030 (Church St.)	62032 (Cemetery)	Wind*
Jul 5		56	SSE
11		34	NNW
17		43	W
23	73	53	W
29	175	-	SE
Aug 4	105	-	S
10	48	24	W
16	180	74	SSE
22	65	58	NNW
28	85	60	WNW
Sep 3	157	98	W
9	67	39	W
15	86	37	S
21	46	26	NNW
27	59	25	NNW
Oct 3	111	144	SSE
9	57	43	WNW
15	72	45	NNW
21	32	17	WNW
27	191	35	SSW
Nov 2	149	112	WNW
8	203	90	S
14	109	51	WSW
20	56	38	NNW
26	77	56	NW
Dec 2	79	68	S
8	45	33	WNW
14	49	19	W
20	51	44	NW
26	29	16	WNW

*Prevailing wind directions.

[+] Values exceeding Ontario 24-hour criterion (120 μg/m³) are underlined.

TABLE 7. Sulphation rates (mg SO_3/100 cm^2/day), Fort Frances, 1976.

Station	Location	Distance(metres) and direction from source*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
62030	Church/Portage	215 NNE	.26	.18	.20	.40	-	.20	.10	.32	.31	.24	.28	.25	.25
62032	Cemetery	990 WNW	.03	.66	.54	.11	.18	.46	.05	-	.19	.08	.15	.12	.23
62033	Nelson/Portage	135 NNE	.16	.22	.46	.71	.51	.74	.27	.48	.45	.54	.70	.25	.46
62034	First/Victoria	590 NE	.14	.16	.14	.16	.16	.16	.03	.11	.21	.12	.17	.12	.13
62035	Legion Building	250 N	.10	.42	-	.22	.30	.44	.07	.31	.38	.22	.30	-	.17
62036	Sinclair/Victoria	295 E	.16	.16	.24	.16	.24	.26	.13	.11	.17	.22	-	.16	.18
62037	Reid/Gillon	1385 ENE	.14	.16	.12	.06	.14	.16	.03	.08	.10	.12	.14	.12	.11

*Source arbitrarily designated as Ontario-Minnesota kraft mill recovery furnace stack.

TABLE 8. Frequency distribution groupings of hourly H_2S concentrations in Fort Frances during 1976.

Month	Days	Concentrations (ppb) 0	1-20	21-49	50-249	250-499	500+	Maximum
		Station 62030						
Jan	5	106	16	0	0	0	0	3
Feb	29	526	153	6	1	0	0	68
Mar	31	383	287	41	15	0	0	96
Apr	30	433	149	47	85	1	0	379
May	31	369	245	54	59	10	0	441
Jun	18	231	118	27	45	5	0	458
Jul	21	258	175	32	52	2	0	282
Aug	26	256	202	86	86	2	0	279
Sep	30	340	235	49	76	0	0	188
Oct	31	355	272	47	57	0	0	178
Nov	28	358	191	76	62	2	0	318
Dec	29	388	277	35	11	0	0	127
Year	309	4003	2320	500	549	22	0	458
		Station 62032						
Aug	28	250	300	48	24	0	0	116
Sep	30	521	66	10	2	0	0	105
Oct	31	621	48	8	0	0	0	34
Nov	29	594	59	4	0	0	0	39
Dec	21	472	40	10	7	0	0	71
Year	139	2458	513	80	33	0	0	116

TABLE 9. Hourly frequency of occurrence and average concentration (ppb) of above criterion H_2S levels by wind direction, station 62030, Fort Frances, 1976.

Month	Wind direction 170-220°	230°	240-260°	Calm	Other	Total
January	nil/nil	nil/nil	nil/nil	nil/nil	nil/nil	nil/nil
February	1/36*	1/43	5/37	nil/nil	nil/nil	7/38
March	39/44	7/37	4/41	4/40	2/36	56/42
April	91/99	11/49	11/61	9/72	11/39	133/85
May	66/123	12/102	15/55	10/62	20/66	123/98
June	39/101	16/94	13/55	nil/nil	9/50	77/86
July	43/83	6/68	8/88	16/116	13/39	86/82
August	91/81	9/58	29/40	33/78	12/44	174/70
September	73/86	4/47	17/33	23/75	8/44	125/73
October	52/74	8/64	11/31	26/66	7/44	104/64
November	77/92	14/63	34/41	11/126	4/114	140/80
December	40/43	1/47	1/23	4/28	nil/nil	46/42
Year	612/86	89/69	148/46	136/77	86/52	1071/75

* 1 = hourly frequency for month.

36 = average of concentrations exceeding 20 ppb.

TABLE 10. Hourly frequency of occurrence and average concentrations (ppb) of above criterion H_2S levels by wind direction, station 62032, Fort Frances, 1976.

Month	Wind direction 110-120°	140-170°	Calm	Other	Total
August	3/33*	48/52	5/44	16/37	72/47
September	nil/nil	8/48	2/33	2/36	12/43
October	nil/nil	7/28	1/24	nil/nil	8/27
November	nil/nil	3/36	nil/nil	1/25	4/33
December	2/35	10/47	nil/nil	5/41	17/44
Year	5/34	76/48	8/39	24/37	113/44

* 3 = hourly frequency for month.

33 = average of concentrations exceeding 20 ppb.

TABLE 11. Wind frequencies (%) favouring H_2S fumigations during monitoring periods in Fort Frances, 1976.

Month	Station 62030				Station 62032		
	170-220°	230°	240-260°	Calm	110-120°	140-170°	Calm
January	19	2	13	6			
February	15	4	17	8			
March	15	3	9	5			
April	16	2	7	6			
May	16	2	3	9			
June	18	3	9	4			
July	15	2	9	12			
August	24	1	7	17	2	20	18
September	20	2	10	15	< 1	15	16
October	13	2	11	17	2	11	18
November	14	3	15	3	nil	5	3
December	16	1	11	11	2	7	7
Year	17	2	10	8	1	13	14

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